Brain computer interfaces

Technology: Brain computer interfaces

Abstract

Over the last decade there have been significant developments in Brain Computer Interface (BCI) technology, mainly driven by research funding initiatives. Accuracy, reliability, usability and aesthetics have all improved and there has been significant effort to transfer this technology from the research lab to the wider community. Commercial products are starting to become available. But who will be the ultimate beneficiaries of the technology? Will BCI benefit people with severe communication difficulties or will it find application as the latest augmentation modality for healthy people in pursuit of new ways to interact with the digital world? Ethical issues of autonomy of the person and justice associated with BCI are explored.

Definition of the technology

According to Pfurtscheller et al., (2010) a BCI must fulfil four criteria:

> "*Direct:* *The system must rely on activity recorded directly from the brain.*
> *Intentional control:* *At least one recordable brain signal, which can be intentionally modulated, must provide input to the BCI (electrical potentials, magnetic fields or hemodynamic changes).*
> *Real time processing:* *The signal processing must occur online and yield a communication or control signal.*
> *Feedback:* *The user must obtain feedback about the success or failure of his/her efforts to communicate or control."*

BCI offers potential control and communication for people without the use of peripheral muscular control (Wolpaw *et al* 2002). It is also the subject of much interest as a communication channel in the world of computer gaming and virtual reality (Nijholt *et al* 2009). Most BCIs utilise the electrical activity (electroencephalogram know as EEG) associated with brain function. Capture of the EEG can take the form of invasive implanted electrodes or non-invasive surface electrodes. Sensory stimulation is sometimes required to alter brain activity and is normally delivered visually, often requiring the user to engage with a task, for example to count the number of occurrences of a 'target' letter in a spelling application. In another approach the user is expected to attempt to alter their own brain electrical activity (often aided by visual feedback), by concentration and active thought, known as Motor Imagery (MI).

Background

The technology eminates from the early electrophysiology laboratory and the first recording of the EEG in 1924 by Hans Berger. Other noted early pioneers included Lord Adrian and Brian Matthews (ink writer recordings) (Grass 1984). By the 1930s Hallowell Davis had set up a laboratory at Harvard Medical School for EEG research and William Grey Walter had measured the well-known 'alpha' brain waves. In 1951 George Dawson recorded an 'evoked' response, using vacuum tubes and analog technology. By the 1960s multichannel EEG was collected by surface electrodes attached to various positions on the scalp and written to a paper chart, as part of routine hospital investigation. Waveforms were visually inspected and classified by trained Neurologists to diagnose conditions such as epilepsy and some forms of mental dysfunction.

The advance of computer technology in the 1990s provided digitization, mass storage, display and methods for powerful signal processing of the temporal EEG, where signals from the brain could be harnessed and transformed to interact with the real and virtual worlds, mediated by the computer. This heralded the era of BCI (Wolpaw et al 2000). In the last decade accuracy, reliability, usability and aesthetics have all been improved by the research and small and medium enterprise communities. More recently BCI has been combined with other neural signals to provide Brain Neural Computer Interface (BNCI) (Alison 2011), which may prove more robust, and hybrid BCI systems are currently under investigation.

Progress in understanding brain function continues to this day and BCI technology no longer belongs in the realm of science fiction (Kübler 2013). The Future BNCI Roadmap (Alison 2011) provides a summary of the progress made and sets out future goals. BCI research continues to be high profile and has received significant funding from government. In April 2013 The USA President (Obama 2013) announced multi-million dollar funding for The BRAIN project, 'Brain Research Through Advancing Innovative Neurotechnologies', scheduled to begin in 2014. It will utilize imaging techniques and computational models, to study the brain in action and better understand how humans think, learn and remember. Similar ambitious research is ongoing in Europe, with the Human Brain project (Human Brain 2013):

> *"The goal is to bring about a revolution in neuroscience and medicine and to derive new information technologies directly from the architecture of the brain."*

Uses of BCI technology

Brain Computer Interface (BCI) technology offers potential for human augmentation in areas ranging from communication to home automation, leisure and gaming. Enhancing the communication mechanisms for those at the greatest risk from social exclusion is an important social responsibility. The communication need has been evidenced by individuals such as Jean-Dominique Bauby, who developed a degenerative disease known as 'locked-in syndrome' (LIS) and subsequently penned his autobiography "*The diving bell and the butterfly"* (Bauby 1998). He achieved this remarkable feat with the aid of his nurse, by using eye-blinks to painstakingly recount his story. Additional clinical investigation is on-going in areas such as stroke rehabilitation (Buch *et al* 2008) and autism (Pineda *et al* 2008).

BCI Deployment

Much of the recent research has endeavoured to make BCI technology more accessible to users, in (European Union funded) projects such as TOBI, BRAIN, Brainable and Back Home (see Allison 2011). Additionally, knowledge transfer has meant that BCI technology is now becoming available directly to the public. For example, Gtec have released a commercial BCI system for spelling, computer control and painting by thoughts (Intendix 2013). BCI mediated games devices for leisure and application development toolkits for further development beyond pure BCI research have become available in the last 2-3 years. It could be that either spelling for communication or alternatively computer gaming becomes the ‘killer app’, forcing BCI technology further into the mainstream. This demonstrates promise for wider deployment.

Ethical issues

The key areas of autonomy, beneficence, non-maleficence and justice, first introduced 30 years ago (see Beauchamp and Childress, 2009) continue to act as a guiding framework for ethics. Beneficence and non-maleficence, underpin all ethical research although it is worth noting that the advancement of BCI technology often requires participation of subjects who themselves may not achieve any **benefit**. Sometimes these subjects may be vulnerable and choose to engage for altruistic reasons, and hence may be considered as research partners.

With regards to **autonomy**, Blain-Moraes *et al* (2012) highlights the ultimate importance of the basic need for effective communication:

> *“the existence of the human-self hinges on successful interaction with others; those who cannot engage in communicative interaction are, consequently, at risk of not being accorded personhood by others.”*

Thus communication clearly has an overarching role in BCI application. Pioneering advances have demonstrated invasive BCI to be appropriate to long-term use (Sellers *et al* 2010); an LIS patient used a BCI with good accuracy for over two years, using implanted electrodes. Surface electrodes are appropriate to shorter term use, and the requirement for easier application has stimulated work in ‘dry’ and ‘water-based’ electrode solutions.

One of today’s high profile ethical debates concerns management of people with disorders of consciousness. These disorders include LIS, minimally conscious state and those in a permissive vegetative state. Diagnosis is not straightforward and sufferers can change category over time. BCI could have a role in establishing whether the person in such an impaired state can *react to* or *understand* external stimuli, and possibly provide a communication channel (BCI equivalent to Bauby’s eye-blinks). Such a possibility offered by BCI could even serve to lessen the individual’s concerns somewhat, e.g. if a sufferer knew that he/she could readily indicate a requirement for higher level pain relief, would this improve their wellbeing? In the longer term, would more LIS patients accept life prolonging treatment, if they knew they could continue to communicate, even if their condition deteriorated further? (BBC website 2013, Nijboer and Broermann 2010).

BCI raises a **justice** consideration, in that those in the greatest need for such technologies often cannot gain access, due to the individualised nature of the technology and the subsequent care support package needed. BCI technology has been demonstrated to work well in many research projects, but BCI will undoubtedly work best for people have little impairment. Hence it may first become an adjunct to gaming platforms, or a way for an athlete to seek a competitive advantage. Is this a worthy result of the significant funding initiatives?

This dilemma has been recognised by the Brain Communication Foundation (2013), which aims to target the technology to the demographic that may be overlooked as they provide the least commercial gain.

For healthy people, controversies include selective enhancement and social stratification. Farrah (2012) defines enhancement:

> "*brain enhancement refers to interventions that make normal, healthy brains better, in contrast with treatments for unhealthy or dysfunctional brains"*.

Vlek *et al* (2012) comments:

> "*if brain enhancement does become effective and popular, there could be pressure to enhance one's brain to keep up with the competition*".

There is already evidence that students will take drugs to give them a competitive advantage in examinations (Cahill 2005). Could BCI based brain training be next? Recently golfer Jason Day used brain training based on wireless EEG to aid the mental side of his game:

> *"If the computer shows I'm using my right brain then I know I am focused",*

Day claimed (ABC News 2013). Others may well follow this example.

However, Nijboer *et al* (2011) raises the need for caution on the widespread use of BCI technology and discusses potential negative side effects:

> "*the possibility of BCI-induced changes in cognitive capacities, psychological continuity or personal identity needs to be considered*".

Could these interventions possibly change mood, alter memory retention or result in changes in personality, for example, by rewiring the neurons in the brain?

It is indeed possible that the BCI technology may not be deployed for people with severe communication difficulty and it could remain the preserve of the healthy. While BCI solutions are now much more usable, it is likely that software may need to be personalized to account for any brain dysfunction. The concentration and engagement with some of the current protocols may well be beyond the ill patient. In addition much support is needed in applying and removing the technology, as with any assistive technology support package and it is this factor, which will increase the cost, and reduce the likelihood of those in most need being deprived of the technology.

There are still deployment bottlenecks. Assuming stable BCI hardware and software, with an easy to use interface, the following are recommendations when deploying the technology to a patient group:

- The electrode interface and cap/headset should be comfortable, and be easily/quickly applied to the correct position (and be as unobtrusive as possible).
- Algorithms should be readily (or automatically) personalized to the ability (any deficit) of the user. Indeed if the user cannot use a BCI then this should be verified at an early stage.
- Signal processing techniques should minimize the need for (time consuming) re-calibration as much as possible.
- Knowledge of BCI as an assistive technology and appropriate applications (e.g. speller, social networking tool) should be disseminated to appropriate health care

professionals (nurse, occupational therapist, rehabilitation therapist, care worker). The above three points require contrasting and possible considerable technical expertise.

Even if the technology falls in price, the support package will always be ‘expensive’ as it will undoubtedly involve an assistant/carer who must assist with set-up and supervise safety critical applications.

Summary

So ninety years after Berger’s pioneering work, where are we now? BCI technology is reaching a level of maturity where it will undoubtedly become usable and useful. Initially, at any rate, this technology will probably benefit healthy people in applications which are not safety critical, such as gaming. This is to be welcomed as it should further stimulate the industry and feed new research. Indeed a secondary aim of much of the (European Union) research funding was to promote wealth. However, it will be an injustice if BCI does not reach and benefit the patient groups that triggered much of the research in the first place. The ethics of BCI, particularly with regard to its deployment to those in greatest need for communication, should therefore continue to be high on the agenda.

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